

TWO TOPICS IN PARTICLE-ANTIPARTICLE MIXING

T.E. BROWDER

Department of Physics and Astronomy, University of Hawaii, 2505 Correa Road, Honolulu, HI 96822, U.S.A

1 Introduction

This paper discusses two experimental issues in the study of particle antiparticle mixing. We propose a new method to extract the ratio $|V_{ts}/V_{td}|^2$ from a measurement of $\Delta\Gamma/\Gamma$ for the B_s meson. This method is experimentally more sensitive than the conventional method for large values of $|V_{ts}|$ but depends on the accuracy of parton level calculations. We then briefly discuss the implications of large CP violation and final state interactions (FSI) in the experimental search for $D^0 - \bar{D}^0$ mixing.

2 A New Method for Determining $|V_{td}|/|V_{ts}|^2$.

The measurement of the mixing parameter $x_s = \Delta m/\Gamma$ for the B_s meson is one of the goals of high energy collider experiments and experiments planned for the facilities of the future. A measurement of x_s combined with a determination of x_d the corresponding quantity for the B_d meson allows the determination of the ratio of the KM matrix elements $|V_{td}|^2/|V_{ts}|^2$ from the ratio¹

$$\frac{x_s}{x_d} = \frac{(m_{B_s} \eta_{QCD}^{B_s} B_{B_d} f_{B_s}^2) \tau_s}{(m_{B_d} \eta_{QCD}^{B_d} B_{B_s} f_{B_d}^2) \tau_d} \left| \frac{V_{ts}}{V_{td}} \right|^2 \quad (1)$$

The factor which multiplies the ratio of KM matrix elements is unity up to $SU(3)$ breaking effects and has been estimated to be of order 1.3². Since time integrated measurements of B_s mixing are insensitive to x_s when mixing is maximal, one must make time dependent measurements in order to extract this parameter. A severe experimental difficulty is the rapid oscillation rate of the B_s meson, as recent experimental limits indicate that $x_s > 8.4^2$ and theoretical fits to the Standard Model parameters suggest that x_s lies in the range 10 – 40.

It should be noted that there is another parameter of the B_s meson which can also be measured, this is $\Delta\Gamma/\Gamma$, the difference between the widths of the two B_s eigenstates. For $|V_{ts}| \sim 0.043$ this could lead to a value of $\Delta\Gamma/\Gamma$ of order 10 – 20% which is measurable at high energy experiments or asymmetric B factories. In parton calculations¹

$$\Delta\Gamma = \frac{-G_F^2 f_B^2 m_B m_b^2 \lambda_t^2}{4\pi} \left[1 + \frac{4}{3} \frac{\lambda_c}{\lambda_t} \frac{m_c^2}{m_b^2} + O(m_c^4/m_b^4) \right] \quad (2)$$

Comparing to the dispersive term, this gives

$$\frac{\Delta\Gamma_{B_s}}{\Delta m_{B_s}} \approx \frac{-3}{2} \pi \frac{m_b^2}{m_t^2} \times \frac{\eta_{QCD}^{\Delta\Gamma(B_s)}}{\eta_{QCD}^{\Delta M(B_s)}} \quad (3)$$

where m_b, m_t are the masses of the b and t quark respectively and terms of order $m_c^2/m_b^2, m_b^2/m_t^2$ are neglected¹. The last factor in the above expression, the ratio of QCD corrections for $\Delta\Gamma$ and ΔM , is expected to be of order unity. All of the above factors in $\Delta\Gamma$ have a common mass dependence of m_b^2 in the leading term. From equations (1) and (3), the ratio x_s/x_d is then given by,

$$\frac{\Delta\Gamma_{B_s}}{\Delta m_{B_d}} = \frac{-3}{2} \pi \frac{m_b^2}{m_t^2} \frac{(m_{B_s} \eta_{QCD}^{\Delta\Gamma(B_s)} B f_{B_s}^2)}{(m_{B_d} \eta_{QCD}^{\Delta M(B_d)} B f_{B_d}^2)} \frac{|V_{ts}|^2}{|V_{td}|^2} \quad (4)$$

We have assumed that the lifetimes of the B_d and B_s mesons will have been measured to sufficient precision to extract this ratio. The above expression assumes unitarity since the leading term which enters in $\Delta\Gamma$ is

$$\lambda_u^2 + \lambda_c^2 + 2\lambda_u \lambda_c \quad (5)$$

which is expressed as

$$(\lambda_c + \lambda_u)^2 = (\lambda_t)^2 \quad (6)$$

via unitarity of the KM matrix. In fact, all determinations of $|V_{ti}|$ which depend on virtual t quarks necessarily rely on the assumed unitarity of the 3×3 KM matrix. The only way to obtain values of $|V_{ti}|$ free from this assumption is through direct on-shell measurements of t decays.

Several authors have pointed out that the quantity $\Delta\Gamma(B_s)$ may be large since there are intermediate final states such as $\bar{B}_s \rightarrow D_s^{(*)+} D_s^{(*)-}$ accessible to both B_s and \bar{B}_s which have appreciable branching states^{3,4}. The calculation of Aleksan, Le Yaouanc, Oliver, Pene, and Raynal³ shows that the parton model estimate and the calculation using exclusive final states agree to within an accuracy of 30%. Given the large experimental uncertainties already present in the determination of the ratio $|V_{ts}/V_{td}|^2$, this is not yet a serious limitation.

In order to measure $\Delta\Gamma/\Gamma$, one must determine the lifetimes of two samples of events. One possibility is to use the large samples of $\bar{B}_s \rightarrow \psi\phi$ events and $\bar{B}_s \rightarrow D_s^{(*)+} \ell^- \nu$ events. The first sample may be dominated by events in a single CP eigenstate as is the case for $B_{d,u} \rightarrow \psi K^*$. This can be verified experimentally by measuring the polarization in this decay. The latter sample of semileptonic decays will be an incoherent mixture of both CP eigenstates. The measured lifetime difference will be $\Delta\Gamma/\Gamma^2$, which can then be used to constrain $|V_{ts}|^2/|V_{td}|^2$. Another possibility is to obtain $\Delta\Gamma$ by fitting the lifetime

distribution of a sample of $\bar{B}_s \rightarrow D_s^{(*)+} \ell^- \nu$ events to the sum of two exponential distributions and allowing for the oscillatory term.

The sensitivity of the two methods can be roughly compared as follows. The ALEPH lower limit on x_s (8.4) corresponds to the lower limit $\Delta\Gamma/\Gamma > 0.033$ (3.3%). A measurement of a 7% lifetime difference corresponds to a central value of $x_s = 15$ for a time dependent oscillation study. For large values of V_{ts} , the method using $\Delta\Gamma$ eventually becomes more sensitive. Good control of systematic effects from the boost correction in $\bar{B}_s \rightarrow D_s^+ \ell^- \nu$ and the lifetime of the background sample are required. Feasibility studies of the technique introduced here have begun at the CDF experiment^{5, 6}.

3 Experimental Search for $D^0 - \bar{D}^0$ Mixing

As was recently noted by Blaylock, Seiden, and Nir⁷ due to final state interaction (FSI) a term proportional to $\Delta M t e^{-\Gamma t}$, which was previously neglected, may appear in the rate of wrong sign D decays (when combining samples of D^0 and \bar{D}^0 mesons) even in the absence of CP violation. Moreover, in some extensions of Standard Model which have large values of both ΔM and significant CP violation¹³, a similar term may arise. Blaylock et al. have suggested that a value of ΔM larger than the present experimental limit can be accommodated if one of these previously neglected terms destructively interferes with the other time dependent terms which arise from mixing (proportional to $t^2 e^{-\Gamma t}$) and from doubly Cabibbo suppressed decays (DCSD) (proportional to $e^{-\Gamma t}$). They suggest that this may invalidate the use of existing limits from time dependent mixing studies at fixed target experiments^{8, 9} to constrain extensions of the Standard Model.

The conclusion of recent work done in collaboration with S. Pakvasa¹⁷ is that, at the present level of sensitivity and with reasonable (though model dependent) values for the phase difference δ , the $\Delta M t$ term which arises from FSI could change the observed event yield for experiments which study the time dependence of mixing by at most 10%. This is not yet a significant systematic experimental limitation. The contribution from the corresponding term proportional to $\Delta M t$ due to CP violation which arises in extensions of Standard Model is highly suppressed. This term is not observable at the present level of experimental sensitivity. However, as emphasized by Liu^{14, 15} and by Wolfenstein¹⁶, this term should not be neglected as experimental examination of the $D^0(t) - \bar{D}^0(t)$ distribution may allow more sensitive searches for $D^0 - \bar{D}^0$ mixing in the future if the CP violating phase is large.

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